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Pozzolanic properties of Waste Agricultural Biomass - African Locust Bean Pod Waste

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ABSTRACT

The increase in agricultural waste such as African locust bean pod have resulted in endangering the life of plants and animals. Researchers have found out ways that this environmental pollution can be of positive relevance by recycling the waste to be re-used or reduce to ensure a cleaner and healthier environment. African locust bean pod was ashed and the pozzolanic properties were investigated. The pod was dried, blended and ashed in a furnace at 500°C for two (2) hours; different analysis was carried out on the ash obtained to prove the pozzolanic properties, such as sieve analysis to determine the particle size distribution; reaction of calcium hydroxide with the ash in relation to time which proved that pozzolanic reactivity increases with time, comparison of hydration of Portland cement with ashed locust bean pod mixture and compressive strength test.

Key words: *Pozzolan, Pozzolanic properties, Pozzolanic reactivity, Compressive strength, African locust bean pod ash*

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INTRODUCTION

These are some agricultural products that are left after the product has been consumed. Such products include rice hull (husk), African locust bean pod, palm kernel shell, fly ash, etc. Waste agricultural biomass can be very useful when recycled.

African Locust bean with botanical name *Parkia biglobosa* is a leguminous plant found in the Savannah region of Nigeria. The botanical name *Parkia biglobosa* was given to it by Robert Brown, a Scottish botanist in 1826. He described the tree as genus of flowering plants in the legume group which belongs to the sub - family Mimosoideae and Leguminosae (Abdoulaye, 2012, Ojewumi *et al*., 2016a, 2016b). *Parkia biglobosa* (African locust bean seeds) is a perennial deciduous tree that grows from 7m to 20 meters high (Teklehaimanot, 2004, Ojewumi *et al*., 2016c). The seeds from the fruits are opened up and are separated from the pods while the empty pod and the pulp is also removed. The composition of the pod includes; fruit weight: 39%, yellowish pulp and seeds: 61% (Sina , 2002). The bark of the tree can be used for the medical care of toothache, leprosy, eye sores, rise in body temperature, hypertension, wounds, ulcer and snake bites. The fermented seeds are nutritional additives to stews and soups as well as source of vital amino acids (Umar, 2005).

Pozzolans are materials that consist majorly silica and alumina [Cook, 1986], they are able to combine in the presence of moisture and chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties as a binding agent [Takemoto & Uchikawa, 1980, Sersale, 1980].

Pozzolans are known to increase durability [Cook, 1986, Mehta 1987, Kitsopoulos *et al*., 1996, Martinez *et al*., 2006, Rojas & Cabrera 2002, Shi 1998, Zhang & Malhora 1995], lower the heat of hydration [Mehta 1987, Shi 1998, Urrutia 1992], increase the resistance to sulphite attack [Cook, 1986, Urrutia 1992, Janoka & Krajci 2003] and reduce the energy cost per cement unit [Shi 1998]. Early nineteenth century, brought about the decrease in the use of lime binders due to the developments that came along with cement but this fact is fast changing because lime binders have been proved to be an environmentally sustainable alternative to concrete. The difficulty of low tensile strength and compressive strength is attributed to concrete.

Pozzolanic reactivity is affected by particle size and specific surface. They give an indication to the shape and structure of the particle obtained. For pozzolanic reaction to occur, pozzolanic materials must possess high specific surface area and silica content [Cachim, 2009]. Speed of pozzolanic reaction enhances strength development which depends on pozzolan type [Massazza, 2007].

2.0 MATERIALS AND METHODS

Raw materials: African Locust bean pod were collected from the producers of fermented African locust bean in Ota, Ogun State, Nigeria. Dangote Portland cement 42.5R which conforms to the BS 12: 1978 (specifications for ordinary and rapid-hardening Portland cement) was used.

2.1 Preparation of Pod: 230 g of African locust bean pod was sun dried for one (1) week until the moisture content was close to 0%. Dried locust bean pod was ashed in a furnace at 500°C for two (2) hours. The ash was then subjected to different analysis.

Figure 1 shows the picture of sun dried pods before ashing.

Figures 2 and 3 show the pictures of dried blended pods and ashed pod respectively.

2.2 Particle size distribution: Screen analysis was carried out with different sieve sizes: 11.20 mm, 3.35 mm, 0.106 mm, 0.150 mm, 0.300 mm, 0.500 mm and pan respectively. The mass retained, cumulative mass retained, percentage passing, cumulative percentage passing and percentage retained on each sieve size were determined.

2.3 Reaction between calcium hydroxide and African locust bean pod ash: 20 g of locust bean pod ash and 20 g of powdered calcium hydroxide were measured and stirred properly in a 500 mL beaker with the addition of 15 mL of water and 5 mL of isopropyl alcohol which was added at intervals. The mixture was oven dried at a temperature of 100°C for 3 hours.

2.4 Pozzolanic reactivity in suspension: 100 mL of saturated $Ca(OH)_2$ was mixed with 20 g of locust bean pod ash in a 250 mL beaker. 15 mL of the solution was taken at different time intervals (5, 10, 15, 20, 25 & 30 minutes respectively) and filtered; the filtrate was titrated against 0.1 M hydrochloric acid (HCl) and amount of calcium hydroxide reacted at each time interval was recorded.

2.5 Preparation of hydrated samples of Ordinary Portland cement and African locust bean pod ash blended cement: 30 g of Ordinary Portland Cement (OPC) and 30 g of African locust bean blended cement (20% weight African locust bean pod ash in Portland cement) was weighed separately and mixed with 10 mL of water. The hydration reaction was continued at room temperature and stopped with 5 mL of isopropyl alcohol and petroleum ether respectively at an interval of 1, 3, 7, 14, 21 and 28 days respectively.

2.6 Compressive strength: Portland cement-locust bean pod ash (20% replacement) was mixed with sand in the ratio 1:3 then with water according to IS:4031 part 4, 1988. The mortars are placed in a mould of 30 x 30 x 30 mm steel mould. The cubes are moulded and stored in water for curing. The cubes are taken out of water and compressive strength was determined at 1, 3, 7, 21 and 28 days respectively.

3.0 RESULTS AND DISCUSSION

Table 1: Particle size distribution

Sieve size (mm)	Weight of sieve (g)	Weight of sieve + sample (g)	Mass retained (g)	Cumulative mass retained (g)	% retained	Cumulative % retained	% passing
11.200	473.30	473.30	0.00	0.00	0.00	0.00	100.00
3.350	444.70	446.25	1.55	1.55	3.26	3.26	96.74
0.106	295.30	339.10	43.80	45.35	92.21	95.47	7.79
0.150	296.70	296.70	0.00	45.35	0.00	95.47	100.00
0.300	314.70	314.70	0.00	45.35	0.00	95.47	100.00
0.500	315.20	315.20	0.00	45.35	0.00	95.47	100.00
Pan	244.10	246.25	2.15	47.50	4.53	100.00	95.47

From table 1, it was observed that the value of mass retained was highest on the 0.106 mm sieve size (92%) which conforms to ASTM C430:2008 proving that locust bean pod ash possess pozzolanic properties.

Figures 4a and 4b show the reaction between ashed pod and calcium hydroxide. Chemical composition of African locust bean pod ash after burning and grinding is shown in table 2. According to ASTM C 618 Standard, substance with less than 10% CaO is classified as Class F pozzolan while that containing 10-30% CaO is Class C pozzolan; therefore, locust bean pod ash is Class C pozzolan with calcium oxide composition of 12.50%. Also, the presence of amorphous SiO_2 in the composition further proves it possesses pozzolanic ability thereby making the reaction of calcium hydroxide in paste possible. The percentage of reactive silicates is about 40.25% while that of cement is about 20.70%.

Table 2: Chemical Oxide composition of African locust bean pod ash

	Composition (weight %)										
System	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	MnO	Na_2O	K_2O	Pb_2O_5	SO_3	L.O.I
African locust bean pod ash	40.25	13.15	9.00	12.50	2.03	0.80	0.95	4.60	7.95	1.50	6.05
Ordinary Portland - cement (OPC)	20.70	5.75	2.50	64.00	1.00	0.20	0.60	0.15	0.05	2.75	2.30

Where

L.O.I = Loss on ignition

Based on the data presented in table 2 above and with ASTM specification C618-92a, 1994, definition, i.e. for a material to be classified as class C pozzolan, it should have SiO_2 minimum of 50%, while for loss of ignition (LOI) a maximum of 6%. Therefore from this study, the ash used can be classified as Class C pozzolan with LOI for the ash to be about 6%. The sum total of the combination of the chemical compounds (SiO_2 +Al_2O_3+Fe_2O_3) was 62.40%, which when compared with standard specifications ASTM specification C681-92a in conjunction with the chemical composition of the ash obtained in table 2; ash of African locust bean pod will fall under the class C mineral admixture and thus can be considered a pozzolan.

Portland cement + locust bean pod ash

$$\text{Portland cement + Locust bean pod ash} + H_2O \longrightarrow \text{Calcium Silicate Hydrate (CSH)}$$

Pozzolanic reactivity in suspension increases with time and this can be seen in Figure 5 which can be attributed to the fact that when calcium hydroxide is dissolved, it gives more Ca^{2+} and OH^- ions, the dissociated ions reacts with amorphous silica in the pod ash at a faster rate as time elapses.

Table 3: Hydration rate

		TIME (DAYS)					
		1	3	7	14	21	28
Initial weight (g)	OPC	30.20	29.80	29.30	27.80	25.70	24.80
	Blended cement	30.50	30.10	29.70	28.30	26.00	25.00

Weight after reaction (g)	OPC	30.50	30.00	29.50	27.90	25.90	25.00
	Blended cement	30.80	30.30	29.80	28.50	26.30	25.20
Weight after drying (g)	OPC	30.00	29.50	29.00	27.50	25.40	24.50
	Blended cement	30.30	29.80	29.40	28.00	25.70	24.70

Where

OPC = Ordinary Portland cement

From table 3, it was observed that the weight of both samples decreased over the days as the hydration reaction continued. Free lime values increases with time resulting in an increase in hydration; blended cement have a lower value because calcium hydroxide obtained during hydration with amorphous silica with locust bean pod ash which helps to determine the reaction of locust bean pod ash as a pozzolanic material during hydration in relation to Ordinary Portland cement (OPC). The types and amount of hydration products formed depend on the duration of hydration, water to cementitious materials ratio, properties of constituent materials, temperature, soluble alkalis, and chemical admixture. The formation of hydration products cause increase in stiffness of cementitious matrix as a function of time. The stiffening behaviour of the matrix is determined by initial and final setting time.

It was observed in figure 6 that compressive strength increased as the days progressed. Increase in cohesion is due to facing surfaces but chemical reaction and action cannot be totally neglected. In relation to locust bean pod ash, hydration products change so does surface factor leading to microstructural and strength changes. Mechanical factors arise due to physical forces between particles leading to the mixing and settling of cement paste [Nachbaur, 2001]. Figure 6 shows the tested moulded blocks in water for curing.

4.0 CONCLUSION

This work concluded that African locust bean pod possess pozzolanic properties. It can be classified as a Class C pozzolan with calcium oxide composition of 12.50%. African locust bean pod is a good pozzolana reacting with calcium hydroxide to form calcium silicate hydrate. Therefore, the dependence on Portland cement as a binder can be reduced. Pozzolanic reactivity of locust bean pod ash increases with time. Compressive strength increases with time.

5.0 ACKNOWLEDGEMENT

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Conflicts of interest: The authors declare that they have no conflict of interest.

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FIGURES

Fig. 1: African locust bean pod after sun drying

Fig. 2: Samples after blending

Fig. 3: Samples after ashing

Fig. 4a: Sample of locust bean pod ash & powdered calcium hydroxide
Fig. 4b: Dried sample of mixture

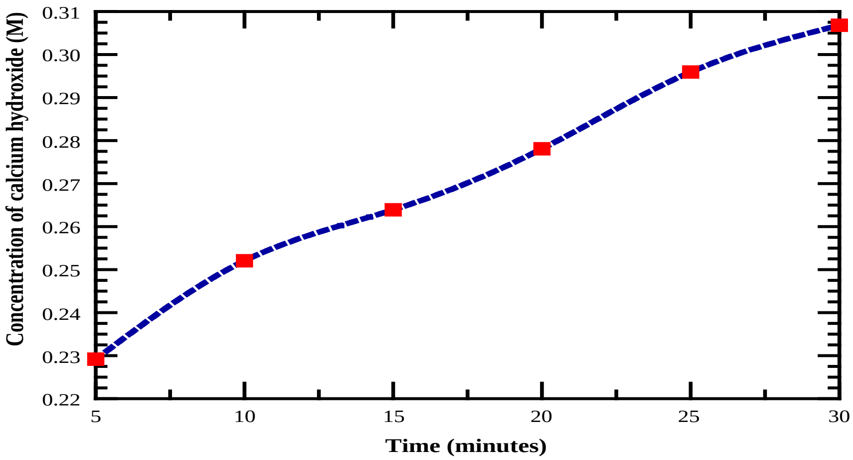

Fig. 5: Pozzolanic reactivity with time

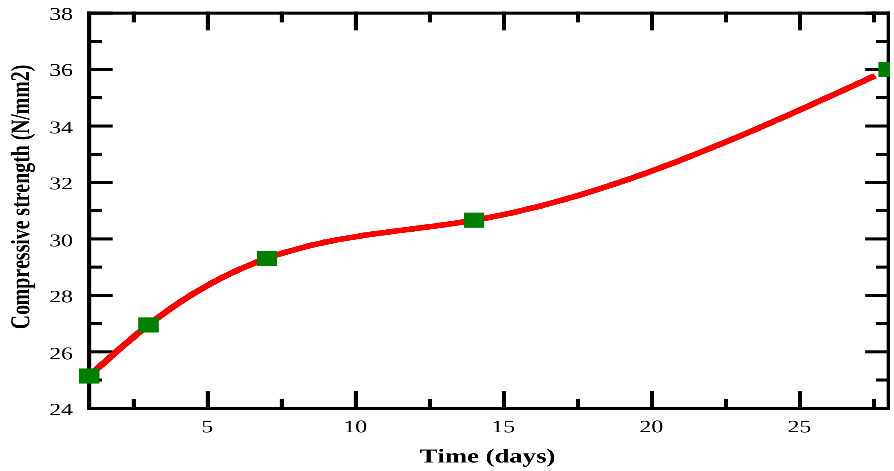

Fig. 6: Compressive strength with relation to time

Fig. 7: Samples in curing tank